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Managing Water in the West

Passive Separator Fish Sorting Studies for Tracy Fish Salvage Facilities

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14. ABSTRACT
The U.S. Department of the Interior's Bureau of Reclamation (Reclamation) is investigating ways to improve fish sorting and holding systems for meeting modern fish protection requirements. Several concepts for fish sorting have been tested using a physical model of proposed on-site Tracy Fish Test Facilities at Reclamation's Water Resources Research Laboratory in Denver. A passive separator was tested to determine its effectiveness for separating large fish from small fish in the horizontal plane. A passive separator is a fixed separator that relies on fish behavior and response to achieve fish passage or sorting, thereby minimizing the potential for injury. The flow approaching the separator is split so that a portion of the flow passes through the separator while the remaining flow continues downstream past the separator; therefore, fish have the option to avoid passage through the separator if they wish. Several factors can be used to encourage the target species to pass through the separator. These include separator angle and channel geometry, as well as hydraulic conditions such as separator approach and sweeping velocity. These variables were investigated to determine what is most effective for separating large and small fish into separate holding areas. As a result of these investigations, test conditions that were conducive to fish separation were identified.

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Passive Separator Fish Sorting Studies for Tracy Fish Salvage Facilities

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by

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Series Editor

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Fish photography by René Reyes, Tracy Fish Collection Facility, Tracy, California.
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EXECUTIVE SUMMARY

The U.S. Department of the Interior's Bureau of Reclamation (Reclamation) is investigating ways to improve fish sorting and holding systems for meeting current fish protection requirements. Several concepts for fish sorting have been tested at Reclamation's Water Resources Research Laboratory in Denver, Colorado, using a physical model of the proposed onsite Tracy Test Facility, Tracy, California.

Passive Separator

A passive separator was the first concept tested to determine its effectiveness for separating large fish from small fish in the horizontal plane. A passive separator is a fixed separator that relies on fish behavior or fish response to achieve fish sorting or passage through the separator, thereby reducing potential predation and minimizing handling injury. Water flowing past the separator is divided, with a portion of the flow passing through and beneath the separator, while the remaining flow continues downstream above the separator, thereby providing fish with the option to either pass through or avoid the separator. Several factors can be used to encourage the target species to pass through the separator, including separator angle, channel geometry, and hydraulic conditions such as separator approach and sweeping velocity. These variables were investigated to determine the configuration and operation that are most effective for separating large and small fish into separate holding areas. The results of these investigations demonstrated that, with appropriate hydraulic conditions and geometry, fish could be effectively separated under passive conditions. The test fish were rainbow trout (*Oncorhynchus mykiss*), Sacramento splittail (*Pogonichthys macrolepidotus*), and fathead minnow (*Pimephales promelas*). Wiper bass were added into the experiments to act as a large predatory species. Wiper bass are a hybrid between striped bass and white bass (*Morone saxatilis* x *M. chrysops*) and have very similar feeding behavior. Best overall separation efficiencies for splittail, rainbow trout, and fathead minnows occurred for a downwelling flow condition combined with a 5-degree separator angle and 4 feet per second (122 centimeter per second) channel velocity. Separator efficiencies were all equal to or greater than 92 percent for this test condition.

Passive-Active Separator

Although tests with the passive separator showed that sorting efficiencies greater than 90 percent could be achieved, additional testing was conducted with a new configuration to determine if sorting efficiencies could be improved. The new configuration consisted of a passive separator similar to what had already been tested, followed by an active separator positioned 4.25 ft downstream from the passive separator. The active separator was positioned so that all water approaching the separator flowed through it and the last 6 inches of the bar rack was dewatered at the downstream end. This setup allowed fish to

first have the opportunity to pass through the passive separator of their on volition to minimize potential injury. However, any fish that was small enough to pass through the passive separator but instead continued downstream was forced to pass through the active separator into a separate holding area. Fish that continued downstream but were too large to pass through either separator were forced to slide along the active separator bar rack into the raceway holding area. For the passive-active configuration, the test fish were rainbow trout, Sacramento splittail, fathead minnow, and white suckers (*Catostomus commersoni*). White suckers were added to act as a demersal species, and wiper bass were, again, the predatory species.

This concept is based on the idea that the potential risk for injury in passing through the active separator will be less than the mortality due to predation that would have occurred had these smaller species passed into the raceway holding area with the larger fish. The passive and active separator bar rack spacing was 19 millimeters for both tests. Tests using this configuration demonstrated that total sorting efficiencies in the range of 99 to 100 percent could be achieved for a single flow condition for all species tested.

INTRODUCTION

The Bureau of Reclamation (Reclamation) has an active fish salvage evaluation program that is investigating ways to improve operations and salvage efficiency of the existing Tracy Fish Collection Facility (TFCF) and to assist with the design of various elements for proposed experimental facilities (Liston *et al*., 2000). An onsite experimental facility was proposed for testing the effectiveness of various fish screening and holding designs to meet current fish protection requirements before constructing replacement fish salvage facilities for the State and Federal water diversions in the South Delta, California.

Fish sorting systems are also critical to the process of returning live fish to the Delta. Currently, the in-ground circular collection system (Reclamation, 1957) is believed inadequate because fish are confined in multiple species assemblages for 8 to 24 hours. Confinement is believed to cause fish to become vulnerable to stress and predation because of these holding conditions. A physical model of a proposed fish separator for sorting and holding fish has been constructed in Reclamation's Water Resources Research Laboratory in Denver, Colorado.

The model provided hydraulic design data and operation data and was used for initial concept evaluations of fish sorting and dewatering using a fisheries-engineering approach. During the initial phase of testing, a passive separator and a passive-active combination of separators were investigated to determine their effectiveness for sorting fish. A literature review (appendix 1) regarding previous fish separation studies provided the basis for the initial design and operation of the model.

METHODOLOGY

Passive Separator

Passive Separator Model

A 1:3 scale physical model of a fish separator for the proposed Tracy Test Facility was constructed in the Denver laboratory. All components downstream from the pump outlet structure were modeled with the exception of the service-holding tank (figure 1). A passive separator was installed in the model for the initial investigations. Although the separator's outer dimensions (10.75 x 2.75 feet [ft] (3.28 x 0.84 meter [m]) were on a 1:3 scale with the model, the diameter of the bars and the spacing between the bars were sized for the prototype in order to perform biological testing with fish under prototype conditions. Thus, this section of the model simulated a ⅓-width sectional model with prototype depth. The separator was constructed of 0.75-inch (in) (1.9-centimeter [cm]) diameter tubing spaced 0.75 in (1.9 cm) apart to allow the desired species to pass through the bar rack and into a separate holding area (figure 2).

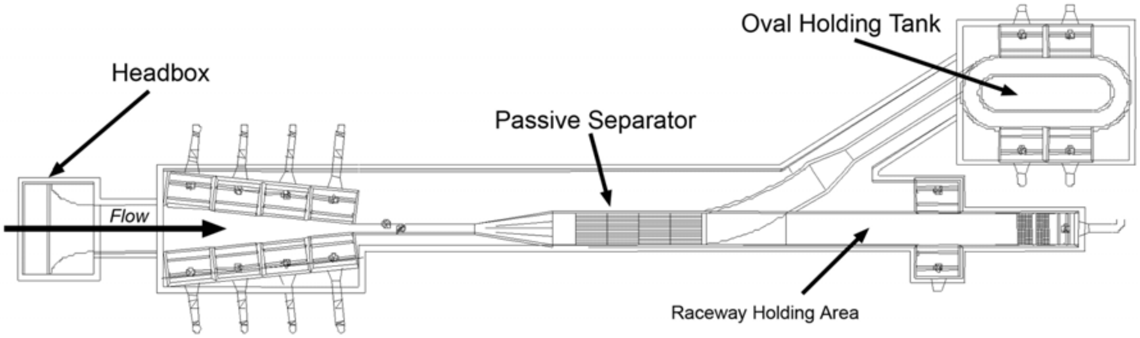

FIGURE 1.—1:3 scale model of the Tracy Experimental Facility fish separator.

FIGURE 2.—Model passive separator bar rack.

Flow to the main channel was supplied using the permanent laboratory venturi system. Auxiliary flow was supplied from the laboratory sump with an 8-in (20-cm) pipe feeding in beneath the upstream edge of the separator (figure 3). The model also included 14 screens and weir dewatering modules. Each of these modules included a fixed vertical screen face followed by an adjustable overflow weir that was used to control and monitor flow rates through each screen. Weir and piezometer taps located throughout the model were measured and calibrated so the depth of flow and discharge could be determined throughout all sections of the model. Separator approach velocities were measured 2 in (5.2 cm) from the bar rack with a Sontek Acoustic Doppler Velocimeter (ADV) probe. Channel velocities were measured with a Swoffer propeller meter at a location 12 in (31 cm) upstream from the leading edge of the separator.

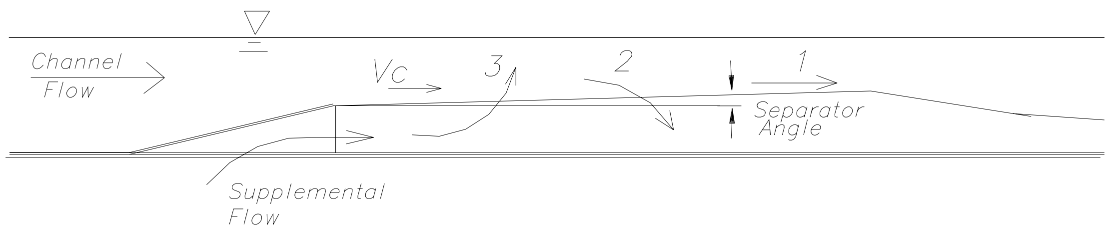

FIGURE 3.—Elevation section schematic of passive separator showing flow regimes tested: (1) even, (2) downwelling, and (3) upwelling. Channel velocity (V_c) is measured 1 ft upstream from the separator.

Passive Separator Investigations

The passive separator was tested to determine its effectiveness for separating large fish from small fish (figure 4). The separator acts as a passive separator because a 6-in minimum flow depth is maintained above the elevation of the separator (this is different from an active separator that is completely dewatered at the downstream end) so that fish can choose to go through the bar rack openings or continue downstream above and past the separator. In addition, channel geometry was designed so that channel flow depth decreased as it approached the separator. This design was based on the concept that fish, sensing the lessening depth, will sound to the bottom of the channel and those fish that are small enough will continue downward through the bar rack openings into the lower channel that leads into the oval holding tank where the separated fish reside (figure 5). The fish that are too large to pass through the bar rack spacing will remain in the flow passing above the bar rack that leads into the raceway fish holding area (figure 6).

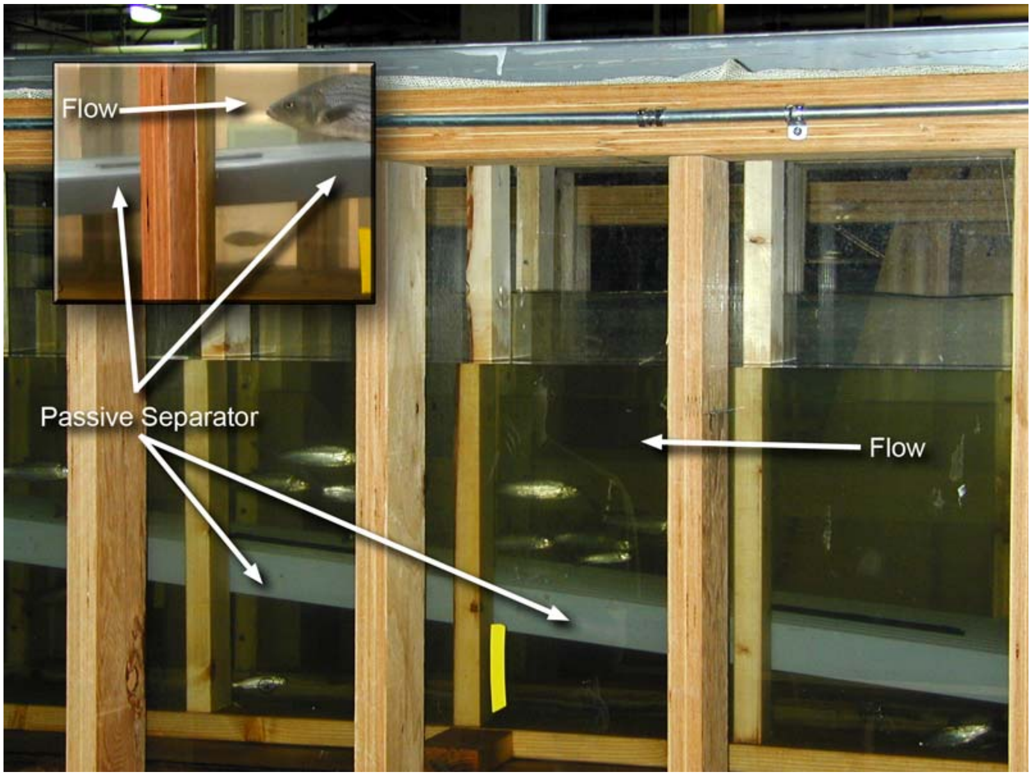

FIGURE 4.—Passive separator prevents large fish (inset) from passing into the area beneath the bar rack.

FIGURE 5.—Model oval holding tank area for separated fish and dewatering weirs.

FIGURE 6.—Model raceway holding area is for fish that are not separated, dewatering weirs, and drum screen.

Passive Separator Test Conditions: Three different variables were investigated to determine what factors would be most effective for separating fish. The three variables investigated were:

(1) Separator orientation or angle
- 0.0° (horizontal)
- 2.3°
- 5.0°

(2) Channel velocity
- 2.0 ft/s (61 centimeter per second [cm/s])
- 4.0 ft/s (120 cm/s)

(3) Separator approach velocity or flow regime
- Even
- Downwelling
- Upwelling

Flow Condition Descriptions: For each separator angle tested, a low and high channel velocity condition was tested at 2.0 feet per second (ft/s) (61 cm/s) and 4.0 ft/s (120 cm/s). Channel velocity, (V_c), was measured at a location in the channel 1.0 ft (31 cm) upstream from the leading edge of the separator. Then several vertical flow regimes, defined by the manner in which flow passes through the bar rack, were tested to determine hydraulic and biological performance. Positive values for separator approach velocity, (V_a), (the velocity component normal or perpendicular to the angled separator face) indicate flow is downward (downwelling) through the bar rack. Negative V_a values indicate upward vertical flow through the bar rack. Negative V_a values indicate upward vertical flow through the bar racks. The flow conditions tested were defined as follows (see figure 3):

- **Even** – This condition is produced when flows above and below the bar rack very similar, producing minimal net flow through the bar rack. Trials were defined as even (E) if V_a was greater than -0.10 ft/s (-3.0 cm/s) and less than +0.10 ft/s (3.0 cm/s). The V_a used for the even test cases are listed in table 1. Average V_c measured upstream from the separator was 2.0 ft/s (60 cm/s) for this test condition.

TABLE 1.—Passive separator test case conditions

Test case	V_c Average channel velocity ft/s (cm/s)	Flow Regime even (E) downwelling (D) upwelling (U)	V_a Average approach velocity ft/s (cm/s)	Separator angle
1A	2.0 (61)	E	0.01 (0.3)	0.0°
1B	4.0 (120)	D	0.10 (3.0)	0.0°
2A	2.0 (61)	E	0.03 (0.9)	0.0°
2B	4.0 (120)	D	0.11 (3.3)	0.0°
3	1.0 (31)	U*	0.10 (3.0)	0.0°
5A	2.0 (61)	E	0.06 (1.8)	2.25°
5B	4.0 (120)	D	0.11 (3.3)	2.25°
8A	2.0 (61)	E	0.07 (2.1)	5.0°
8B	4.0 (120)	D	0.13 (4.0)	5.0°
9B	4.0 (120)	Strong D	0.23 (7.0)	5.0°

*Flow direction is upward.

- **Downwelling** – This condition occurred when the average V_a was > 0.10 ft/s and flow through the bar rack was downward. This test was conducted to determine if fish would follow a net downward flow through the bar rack. V_a values for downwelling trials were ≤ 0.13 ft/s to prevent undesirable turbulence near the downstream end of the separator. Therefore, average V_a downwelling conditions ranged from 0.10 to 0.13 ft/s (3.0-4.0 cm/s). The V_c average measured upstream from the separator was 4.0 ft/s (120 cm/s) for all downwelling flow conditions.

- **Strong downwelling** – To test the effect of greater downwelling flow conditions on separator efficiencies, the separator model was modificed to minimumize turbulence in order to run one additional test case using higher V_a. The average V_a for this trial was 0.23 ft/s (7.0 cm/s), referenced as test case 9B in table 1. The average V_c measured upstream from the separator was 4.0 ft/s (120 cm/s) for the strong downwelling flow condition.

In addition to the above test conditions, an upwelling flow condition was tested. This condition could be produced only with the separator oriented horizontally (0°) and with an average channel velocity of 1.0 ft/s (31 cm/s):

- **Upwelling** – This condition occurred when V_a was negative, producing upward net flow through the bar rack. This test was conducted to determine if the upward flow through the bar rack would serve as an attraction flow that fish would follow downward through the rack. The average V_a for this condition was -0.1 ft/s (-3.0 cm/s) (upward) with a maximum upward normal component of -0.13 ft/s (-4.0 cm/s) measured at the upstream section of the separator.

Passive-Active Separator

Passive-Active Separator Model

The original passive separator model was modified so that an active separator could be positioned downstream from the passive separator. The passive separator used for this series of tests remained 10.75 ft in length but was reduced to a width of 1.33 ft and was angled at 5.0°. A 2- x 1.3-ft active separator was positioned beginning 4.25 ft downstream from the downstream end of the passive separator (figures 7 and 8).

The active separator was sloped downward at 2° angle to help facilitate larger fish sliding on the bar rack into the raceway holding area (figure 9). Each separator was constructed of 0.75-in (1.9-cm) diameter tubing spaced 0.75 in (1.9 cm) apart to allow smaller species to pass through the bar rack.

A third holding area called the active-holding area was created for the actively separated fish. This was accomplished by splitting the original raceway holding area into two sections and extending the active holding channel partially below the raceway section and beneath the active separator (figure 10). As a result, fish that passed through the active separator passed into the lower channel and into the active holding area.

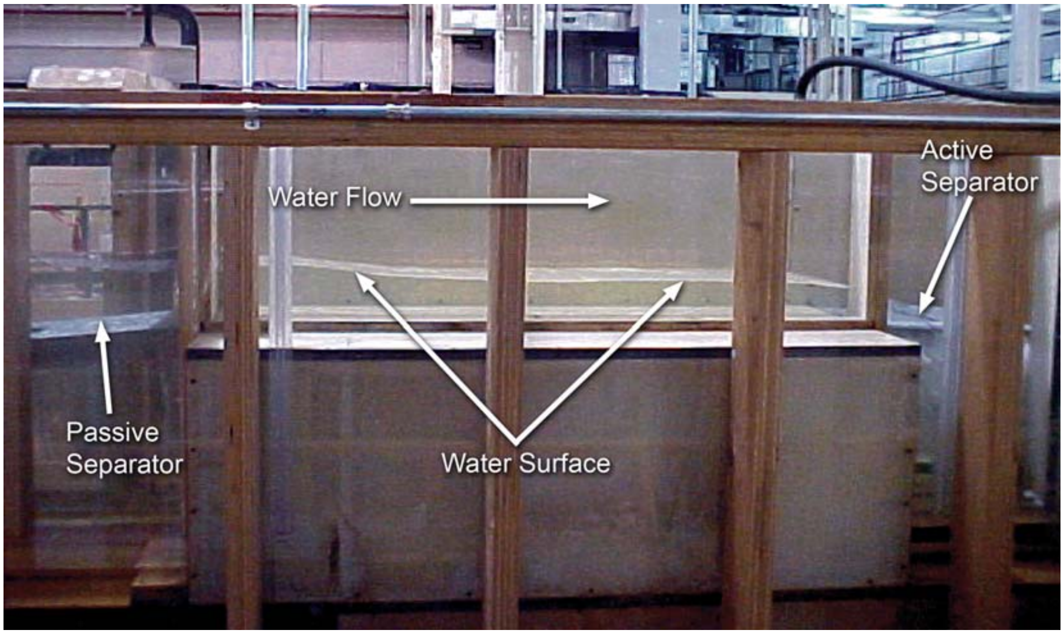

FIGURE 7.—Passive-active separator model, looking through Plexiglas side viewing window.

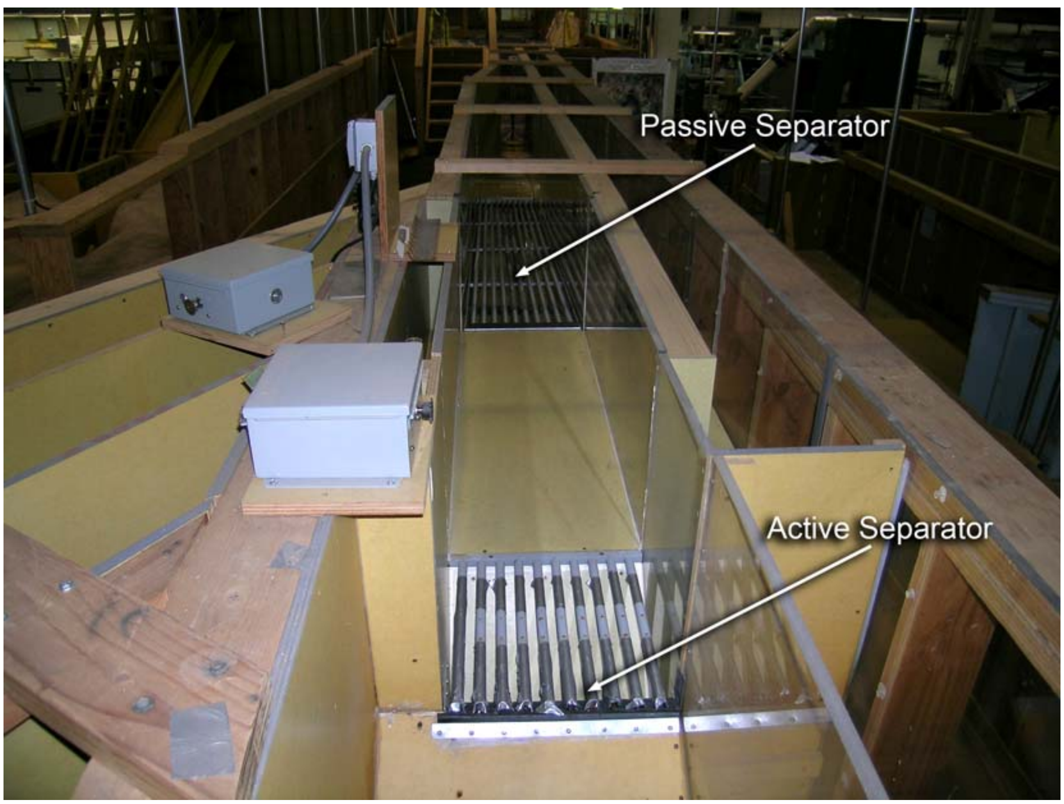

FIGURE 8.—View looking down on passive and active separator bar racks.

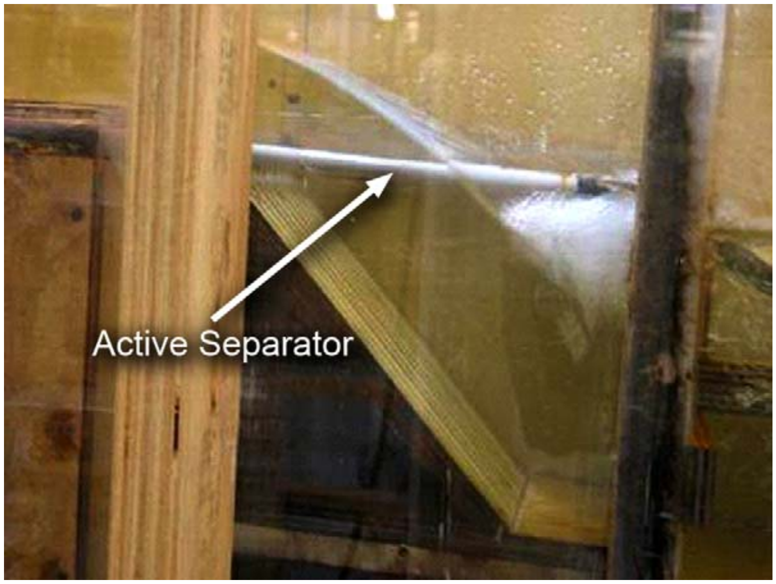

FIGURE 9.—Active separator, looking through Plexiglas side viewing window.

FIGURE 10.—A divider wall added to the raceway provides separate holding areas for actively separated small fish and large fish that are not separated.

Passive-Active Separator Investigations

For this series of investigations, various downwelling conditions in the active separator were controlled with flows through the passive separator. For each test condition, a minimum flow depth 6-8 in was maintained at the downstream end of the passive separator by adjusting the overflow weirs located within the oval tank structure. Flow to the main channel was supplied using the permanent laboratory venturi system and was used to control average channel velocity measured at the leading edge of the passive separator. One less point of control (since flow could no longer be controlled into the raceway area downstream from the separators), produced a slight downwelling flow condition. For this series of conditions, the auxiliary flow feeding beneath the passive separator was eliminated for simplification. The flow conditions are listed in table 1.

In addition, one test condition, PAV2SL, was added with the passive separator spotlighted to determine what effect, if any, illumination would have on sorting efficiencies. For this test condition, flows were identical to test condition PAV2 and spotlights were positioned at each end and above the passive separator. The spotlights were two General Electric dual 500-watt incandescent bulbs placed about 8.5 ft (2.6 meter [m]) above the water surface and directed downward to light the full length of the passive separator bar rack.

Test Methods

Each test condition consisted of three trials. All trials began with 25 individuals from each species (splittail, rainbow trout, and fathead minnow) and were introduced into the flow at the upstream entrance into the model referred to as the headbox area (figures 1 and 11). Prey fish were held in ~80-gallon (gal) (~300-liter [L]) insulated rectangular tanks and predator fish held were held in ~125-gal (~475-L) insulated cylindrical tanks adjacent to the separator flume (figure 12). Fish holding tanks used the same water as the separator flume. Almost all of the prey test species were physically small enough to pass through the openings in the separator (see table 2 for fish size statistics). Ten wiper bass (wipers) were introduced into the flow for each test trial to act as the predatory species. However, less than 10 percent of the wipers were physically small enough to pass through the separator. Wipers were fed about 1 hour before each trial to minimize predation losses during experiments.

FIGURE 11.—Headbox area where prey (splittail, rainbow trout, and fathead minnow) and predator fish (wiper) are introduced to experiments.

FIGURE 12.—Fish holding tanks adjacent to separator flume. Inset shows close-up of experimental fish.

TABLE 2.—Test species information: total number used, average total length, average width, and size range measured in mm for each passive test condition

Test Condition		Wiper				Splittail				Rainbow Trout				Fathead Minnow			
		Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range
1A	All Fish	30	260.6	32.9	173-313	75	123.7	11.9	95-163	73	39.8	4.9	31-47	70	36.5	4.5	25-43
	No Decision	24	256.8	33.2	173-313	20	119.3	11.6	106-142	36	40.7	4.9	36-47	24	37.0	4.8	31-43
	Separated	0				46	125.5	11.7	95-163	27	39.3	4.8	31-43	33	36.4	4.4	25-43
	Not-Separated	6	275.7	32.0	175-313	9	125.3	12.8	110-144	10	39.0	5.3	35-45	13	36.1	4.0	33-41
1B	All Fish	30	250.8	33.0	165-310	75	124.5	12.8	95-155	67	38.3	4.9	29-47	68	52.7	6.4	38-64
	No Decision	16	256.4	33.7	166-310	25	121.3	12.7	97-150	7	40.3	5.3	38-43	10	58.7	7.2	51-64
	Separated	0				40	126.0	12.8	95-149	42	38.7	5.0	33-47	53	51.3	6.3	38-60
	Not-Separated	14	244.9	32.3	165-303	10	127.7	13.1	101-155	18	37.1	4.5	29-45	5	48.8	5.4	40-54
2A	All Fish	30	228.6	28.8	153-311	74	126.3	12.1	104-166	71	39.6	4.3	25-52	68	40.1	4.7	33-64
	No Decision	12	240.6	31.5	153-311	25	120.7	12.6	104-152	24	40.0	4.1	33-50	20	44.4	4.8	35-64
	Separated	0				43	125.3	11.8	109-155	41	38.2	4.4	25-52	45	37.7	4.6	33-54
	Not-Separated	18	220.6	27.0	160-304	6	136.5	12.7	120-166	6	44.5	4.5	35-52	3	38.3	4.8	36-40
2B	All Fish	30	248.8	33.8	131-324	74	124.8	11.9	95-177	70	39.9	4.8	29-65	74	53.9	6.1	43-69
	No Decision	18	253.8	32.7	163-305	39	123.6	12.3	95-143	10	42.2	5.0	35-65	30	57.1	6.2	43-69
	Separated	0				25	127.0	11.9	96-177	40	39.7	4.7	29-45	39	52.3	6.0	43-67
	Not-Separated	12	240.9	35.7	131-324	10	123.2	10.6	96-149	20	39.2	4.7	32-47	5	48.8	6.0	45-62
3	All Fish	30	196.2	22.2	152-275	75	126.8	11.5	100-182	74	43.2	4.8	36-54	68	40.0	4.6	31-66
	No Decision	10	215.3	25.3	152-275	10	121.7	12.2	105-168	53	42.7	5.0	36-53	39	41.7	4.5	32-66
	Separated	0				52	127.7	11.4	100-178	6	43.5	4.3	40-48	16	39.8	5.0	34-53
	Not-Separated	20	186.6	20.7	159-249	13	128.0	11.5	111-182	15	44.1	4.8	40-54	13	36.4	4.2	31-44
5A	All Fish	30	206.2	24.4	146-283	75	166.3	17.5	131-225	67	59.4	6.6	42-80	72	61.0	7.1	51-81
	No Decision	14	190.7	21.9	146-266	7	162.6	17.3	144-175	22	59.0	6.6	46-76	16	59.8	7.1	53-81
	Separated	0				54	158.1	16.2	131-191	18	57.3	6.5	45-75	54	61.6	7.1	51-80
	Not-Separated	16	219.8	26.5	193-283	14	185.6	20.6	163-225	27	61.2	6.6	42-80	2	61.0	6.5	61
5B	All Fish	30	207.8	23.3	143-331	73	167.1	14.6	126-233	70	57.5	4.6	44-87	70	58.6	4.7	39-72
	No Decision	0				2	219.5	17.5	210-229	26	59.8	4.7	44-87	26	59.8	4.7	52-72
	Separated	2	144.0	13.8	143-145	50	157.9	14.3	126-189	35	55.9	4.5	44-72	38	59.3	4.9	51-68
	Not-Separated	28	212.3	24.0	153-331	21	175.4	14.9	142-233	9	55.7	4.4	46-72	6	50.2	4.0	39-56
8A	All Fish	30	192.8	22.0	142-278	72	157.7	15.7	127-207	69	49.9	5.1	36-65	67	43.3	4.5	34-66
	No Decision	21	190.8	21.8	143-278	5	152.0	15.8	130-185	33	49.5	4.8	36-65	5	41.2	4.0	38-45
	Separated	1	142.0	14.0	142	58	155.5	15.1	127-180	12	48.5	4.5	37-65	50	43.7	4.6	34-66
	Not-Separated	8	204.4	23.5	152-258	9	169.0	17.9	143-207	24	51.0	5.7	40-65	12	42.8	4.1	39-54
8B	All Fish	30	204.4	23.7	145-275	70	164.6	15.3	130-200	65	52.6	4.4	39-68	56	46.4	4.6	38-65
	No Decision	1	150.0	14.0	150	5	183.0	18.3	157-199	33	54.3	4.5	41-68	6	49.0	4.4	43-63
	Separated	2	160.5	17.3	149-172	60	160.2	14.8	130-200	30	51.6	4.4	43-64	46	46.1	4.7	38-65
	Not-Separated	27	209.7	24.5	145-275	5	175.0	15.1	150-196	2	42.0	3.5	39-45	4	44.8	3.8	39-50
9B	All Fish	30	216.9	25.9	146-291	74	169.6	17.4	133-202	69	72.3	7.2	49-95	43	45.6	4.8	35-60
	No Decision	2	213.0	25.0	212-214	7	178.3	16.4	148-200	20	79.9	7.1	64-95	4	52.0	5.3	47-55
	Separated	1	150.0	18.0	150	56	167.0	17.3	133-202	38	70.1	7.1	49-89	39	44.7	4.8	35-60
	Not-Separated	27	219.7	26.3	146-291	8	173.8	19.6	145-190	11	71.9	7.5	58-88	0			

Each passive separator test trial was conducted for 30 minutes (min), and fish were crowded from the headbox (where the fish are introduced into the flume) to the throat of the flume at 10, 20, and 28 minutes of elapsed time. This was done by placing a 0.25-in (0.6 cm) mesh seine net at the upstream end of the headbox and then moving the seine downstream until the narrow throat of the flume was reached.

Each passive-active test trial was also conducted for 30 min. However, the method for crowding the fish from the headbox area was improved by installing a 0.19-in (0.48 cm) mesh seine net that blanketed the bottom and sides of the flume so that only one pass of the seine was necessary. As a result, fish were crowded from the headbox for each test case after 20 minutes of elapsed time. Although the splittail for this series of experiments were less than 19 mm wide, the average size of splittail for the passive-active tests was smaller than those that had been used in the previous passive-only experiments (table 3).

At the end of each experiment, the separator model was dewatered and the fish were recovered from their respective locations, counted and then measured. Each test case was evaluated for separation efficiency for sorting fish. Average passive separator approach velocities were measured with a Sontek ADV probe at the centerline of the bar rack at four positions equally spaced along the length of the separator. Separator approach velocity is always given in terms of the component normal to the separator.

TABLE 3.—Test species information: total number used, average total length, average width, and size range measured in mm for each passive-active test condition

Test Condition		Wiper				Splittail				Rainbow Trout				Fathead Minnow				White Sucker			
		Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range
PAV2	All Fish	90	280.9	34.5	167-416	74	55.2	5.1	44-68	222	92.7	9.3	61-132	190	57.8	6.1	42-80	72	103.7	10.3	85-136
	No Decision	49	284.5	35.1	167-416	0				31	91.4	9.4	66-123	22	52.3	5.8	42-65	5	106.8	10.2	94-120
	Separated	1	207.0	22.0	207	71	55.3	5.2	44-68	186	92.9	9.2	61-132	164	58.2	6.1	43-80	66	103.4	10.3	85-136
	Not-Separated	40	278.4	34.1	173-385	3	53.3	4.3	51-55	5	95.0	9.0	73-117	4	53.5	6.3	47-63	1	105.0	13.0	105
PAV3	All Fish	60	303.8	38.0	234-395	69	56.4	4.9	43-70	154	117.7	12.8	56-160	137	52.5	5.2	35-70	144	108.7	10.7	86-130
	No Decision	34	309.4	38.5	235-395	1	58.0	7.0	58	16	127.9	14.5	105-157	28	49.0	5.4	35-58	14	114.3	11.7	90-124
	Separated	0				65	56.3	4.8	43-70	127	116.0	12.6	56-160	99	53.9	5.2	35-70	127	108.3	10.6	86-130
	Not-Separated	26	296.6	37.3	234-345	3	58.7	5.5	51-65	11	122.9	12.9	80-146	10	48.3	4.9	40-60	3	98.7	10.0	90-106
PAV4	All Fish	60	292.5	34.8	140-423	75	56.0	5.0	45-64	146	74.8	6.6	45-105	123	52.4	4.9	31-76	144	104.5	9.2	85-156
	No Decision	5	343.6	42.8	259-393	0				8	74.1	5.7	60-90	14	46.3	3.7	38-62	17	107.3	10.2	95-130
	Separated	7	155.6	14.6	140-174	71	56.0	5.0	45-64	135	74.7	6.6	45-105	109	53.2	5.1	31-76	125	104.2	9.0	85-156
	Not-Separated	48	307.1	36.9	153-423	4	57.3	5.3	54-64	3	81.3	8.3	72-87	0				2	96.5	10.5	90-103

RESULTS AND DISCUSSION

A literature review of fish separator technology is provided in Appendix 1.

Passive Separator

Efficiencies for fish passage through the passive separator were calculated for each species of fish for each test condition (three trials combined) and are given in table 4. For each test condition, the corresponding channel and average separator approach velocity, separator angle, and flow regime are also listed in table 4. Efficiencies were calculated based on the number of fish that passed through the passive separator into the oval holding tank, divided by the total number of fish that passed into the oval holding tank, plus the total number that passed into the raceway area, so that:

$$\text{Percent efficiency} = \frac{\text{(No. of fish recovered from oval holding tank)}}{\text{(No. of fish recovered from oval holding tank + raceway)}} \text{x100}$$

TABLE 4.—Passive separator efficiencies for test species with test case conditions

Test Case	Average Channel Velocity ft/s (cm/s)	Flow Regime Even (E), Downwelling (D), Upwelling (U)	Average Approach Velocity ft/s (cm/s), (+) indicates flow direction is upward	Separator Angle	Separation Efficiency for test case trials (n=3) showing mean efficiencies for test species with standard error (SE)					
					Splittail		Rainbow Trout		Fathead Minnow	
					Mean Efficiency	SE	Mean Efficiency	SE	Mean Efficiency	SE
1A	2.0 (61)	E	.01 (0.3)	0.0°	84	8.6	73	10.4	72	6.0
1B	4.0 (120)	D	.10 (3.0)	0.0°	80	4.2	70	4.4	91	1.1
2A	2.0 (61)	E	.03 (0.9)	0.0°	88	5.0	87	9.9	94	4.2
2B	4.0 (120)	D	.11 (3.3)	0.0°	71	9.6	67	4.0	89	3.1
3	1.0 (31)	U	-.10 (-3.0)	0.0°	80	4.4	29	21.7	55	7.1
5A	2.0 (61)	E	.06 (1.8)	2.25°	79	2.8	40	3.4	96	2.0
5B	4.0 (120)	D	.11 (3.3)	2.25°	70	7.6	80	7.3	86	7.2
8A	2.0 (61)	E	.07 (2.1)	5.0°	86	4.6	33	2.4	81	7.5
8B	4.0 (120)	D	.13 (4.0)	5.0°	92	4.1	94	3.2	92	5.6
9B	4.0 (120)	Strong D	.23 (7.0)	5.0°	88	4.3	78	5.1	100	0.0

Efficiencies were calculated based only on those fish that had either gone through the separator or past the separator by the end of each trial. Fish that remained in the headbox or above the separator at the time the experiment ended were removed from the efficiency calculation. Table 4 demonstrates that:

(1) Best overall efficiencies for splittail, rainbow trout, and fathead minnows occur for a downwelling flow condition separator angle = 5.0° and V_c 4.0 ft/s (120 cm/s) (test case 8B). Separator efficiencies were ≥ 92 percent for this condition.

(2) Poorest overall efficiencies occurred during upwelling flow conditions (test case 3).

(3) In addition to test case 3, poorest efficiencies for rainbow trout occurred mainly at low channel velocities the separator angle <> 0.0° or ≠ (tests cases 5A and 8A).

Passive-Active Separator

For the passive-active configuration, passive and total separator efficiencies for sorting fish were calculated for each species of fish for each test condition (three trials combined) and are given in table 5. Efficiencies for the passive and active separators were calculated based on the number of fish that passed through the separator into their respective holding area, divided by the total number of fish that passed into the oval holding tank, plus the total number that passed into the raceway area, plus those that passed into the active-holding area (AHA), so that:

$$\text{Percent efficiency} = \frac{\text{(Fish in oval holding tank)}}{\text{(Fish in oval holding tank + raceway + AHA)}} \text{ x100}$$

$$\text{Percent efficiency} = \frac{\text{(Fish in AHA)}}{\text{(Fish in oval holding tank + raceway + AHA)}} \text{ x100}$$

TABLE 5.—Passive and passive-active total separator efficiencies

Test Case	Passive Efficiencies (PE) and Total passive-active combined Separator Efficiencies (TSE)							
	Splittail		Rainbow Trout		Fathead Minnow		White Sucker	
	PE (percent)	TSE (percent)	PE (percent)	TSE (percent)	PE (percent)	TSE (percent)	PE (percent)	TSE (percent)
PAV2	50	96	81	98	77	95	97	99
PAV3	51	95	92	100	78	98	97	100
PAV4	35	95	82	96	79	100	93	97
PAV2SL	80	100	81	100	74	100	94	99

Total efficiency was calculated by adding the passive and active separator efficiencies together. Fish that remained in the headbox or above the separator at the time the experiment ended were not included in the efficiency calculation. Table 5 shows that total combined (n = 3) passive-active efficiencies for all test cases and species are ≥ 95 percent.

CONCLUSIONS

Passive Separator

Statistical Analysis of Results

For the passive-only configuration, a statistical analysis was conducted for two separator angles at 2.25° and 5.0°, two velocities at 2.0 ft/s (61 cm/s) and 4.0 ft/s (120 cm/s), and two flow conditions (downwelling and even flow). Appendix 2 discusses the details of this analysis. The conclusions that can be drawn from the analysis are:

- A strong downwelling condition promotes efficiency for a poor swimmer.
- Separator angle efficiencies were not statistically significant.
- Higher channel velocities produce higher efficiencies for rainbow trout.

General Observations

In addition to the results already presented, some general observations were made during the experiments:

- During low channel velocity test conditions (< 2.0 ft/s or 61 cm/s) fish tended to remain above the upstream ramp approaching the separator.

- The upwelling condition (test case 3) produced the lowest overall efficiencies compared with the other test conditions. Many fish held position above the separator where the upwelling flow was strongest.

- Low channel velocities (≤ 2.0 ft/s or 61 cm/s) allowed splittail and rainbow trout to move upstream and downstream at will. As a result, many fish swam into the raceway (sometimes in schools), stayed there for a period of time, and then swam back upstream to the separator. This behavior was noted and occurred during low channel velocity experiments.

- Efficiencies may be higher for rainbow trout at higher channel velocities because they are more likely to seek refuge at locations of lower velocity near the bottom of the channel. As a result, more rainbow trout passed through the separator during higher channel velocity test case experiments.

- A few splittail sought refuge from the high channel velocity flow condition of 4 ft/s (122 cm/s) by bracing themselves between the separator frame and the sidewall; therefore, efficiencies may be slightly increased if the separator can be structurally designed to maintain a 0.75-in (1.9-cm) clearance from the sidewall along most of its length.

- High auxiliary pump flows (i.e., with exit velocities >~2.5 ft/s or 76 cm/s) reduced the number of fish holding directly beneath the separator and, therefore, should reduce the number of fish stranded in this area during fish recovery.

- Fish recovery seems to be most effective with flume floor slopes greater than about 3 degrees to prevent stranding fish.

Passive-Active Separator

Statistical Analysis of Results

For the passive-active configuration, Analysis of Variance, (ANOVA) was performed to test mean passive efficiency and mean total efficiency for the spotlighted condition. ANOVA was also performed for the three passive-active separator conditions (Approach Velocity and Channel Velocity): (1) $V_a = 0.20$ ft/s and $V_c = 2.0$ ft/s, (2) $V_a = 0.30$ ft/s and $V_c = 3.0$ ft/s, and (3) $V_a = 0.40$ ft/s and $V_c = 4.0$ ft/s. Appendix 2 discusses the details of this analysis. ANOVA results suggest:

- A spotlighted condition promotes mean passive separator efficiency for splittail; however, no difference was detected for mean total efficiency for any test species with and without lights.

- No statistically significant differences were detected for mean passive and mean total efficiencies for separator configurations ($V_a = 0.20$ ft/s and $V_c = 2.0$ ft/s, ($V_a = 0.30$ ft/s and $V_c = 3.0$ ft/s), and ($V_a = 0.40$ ft/s and $V_c = 4.0$ ft/s) for any species.

- When ($V_a = 0.20$ ft/s and $V_c = 2.0$ ft/s) and ($V_a = 0.30$ ft/s and $V_c = 3.0$ ft/s) are pooled and compared against ($V_a = 0.40$ ft/s and $V_c = 4.0$ ft/s), slower V_a does influence mean passive and mean total efficiencies for splittail in a statistically significant manner.

General Observations

For the passive-active configuration, table 5 demonstrates that:

- Highest passive and overall efficiencies occurred for test condition PAV2SL with spotlighted test conditions. In this case, all passive sorting efficiencies were above 74 percent and total efficiencies ranged from 99 to 100 percent for all species tested.

- During the spotlighted test condition, observations indicated that fish had a tendency to dive head forward through the passive separator openings immediately upon entering the spotlighted area.

- Spotlighting the passive separator increased passive separator efficiencies for splittail by 30 percent for identical flow conditions. However, more trials may be necessary to confirm that improved efficiencies can be repeated.

- Test case PAV3 produced the best passive efficiencies without spotlighted conditions.

- Differences in passive separator efficiencies between those calculated for the passive-only trials and the passive-active separator trials may be attributed, in part to the difference in flow conditions immediately downstream from the passive separator. In the passive-only separator experiments, velocities measured at a position about 1.5 ft downstream from the passive separator showed a deceleration of 10 to 30 percent. In the passive-active test trials, velocities measured at the same position showed an acceleration of about 30 percent caused by flow dropping through the active separator.

- Although the data presented here do not include conditions tested with auxiliary flow supplied beneath the leading edge of the passive separator, observations indicated that using this auxiliary supply beneath the separator helped deter fish from holding beneath the passive separator, thus resulting in fewer stranded fish during the dewatering and recovery process.

- Adjusting the weir control for the active-holding area suggested that it could be used to cause a small overflow on the downstream end of the active separator to provide a water cushion for the large fish sliding on the bar rack (figure 11). This also provided a steady flowthrough water supply for the raceway holding area and providing auxiliary water for the raceway area was not necessary. As a result, this adjustment is recommended during all operations.

FIGURE 13.—Allowing overflow at the downstream end of active separator helps facilitate downstream movement of large fish and debris.

DEBRIS

Background

Debris collecting on the separators is a major concern because it can block fish passage through the separators and can cause a change in predetermined flow conditions that were set up to help influence desired fish behavior. Debris experiments were conducted using Brazilian elodea, *Egeria densa,* and common elodea, *Elodea canadensis,* because these are species common to the TFCF, cannot flow easily past the separators, and are likely to become wrapped around the tubing, clogging the separator bar rack. For the debris tests, the passive-active test configuration was used so that both the passive and active separators could be tested simultaneously.

Objective

The objective of the debris study was to determine an effective means for removing debris from the separator bar racks and to keep the debris moving downstream so that it would not affect flow conditions set up to influence fish behavior. The goal was to move the debris downstream into the holding areas where it could more easily be removed from the flume using other experimental techniques.

Investigations and Results

Debris was injected into the flow about 3 ft upstream from the passive separator for 3 test conditions. Initial tests showed that debris readily passed through the bars parallel to the flow but had a tendency to wrap around the cross beams supporting the bar rack (left), especially at the downstream end (right) (figures 14a and 14b). Debris also collected on the active separator at the downstream end where the separator became dewatered (figure 15).

Several different configurations of rotating rollers were tested. The results from these experiments demonstrated that the most effective method for passing debris downstream from the passive separator was to replace the cross members supporting the bar rack with 1-in diameter rotating rollers (figure 16). The rollers were rotated slowly using a motor and drive chain located on the outside wall of the flume. Coating the rollers with a nonskid material provided the rollers with enough friction to catch debris and pass it on downstream. Experiments showed that the coating was essential to the design because without the coating, the rollers would slide beneath the debris without moving it.

To remove debris at the downstream end of the passive separator where it transitioned into a solid platform required a slightly different solution. A larger 2-in diameter roller was positioned with the top elevation about a half-inch above the elevation of the downstream platform (figure 17). This configuration allowed debris to be carried over the top of the roller and downstream by the flow without catching in the joint located between the roller and downstream platform. This setup proved successful as an effective means for continuously moving debris downstream past the passive separator.

A similar setup was used to remove debris from the active separator. A 2-in diameter roller coated with a nonskid material was positioned at the downstream end of the separator (figure 18). This time, the roller was positioned beneath the bar rack so it would not interfere with fish sliding into the raceway holding area. Backflow controlled by the active holding area weir was used to provide overflow near the downstream end of the active separator to facilitate moving debris down to the roller (see figure 11). Once the debris contacted the roller, it was easily carried downstream past the active separator and into the raceway holding area.

FIGURE 14.—Debris collects on (a) cross members supporting bar rack and, more notably, at (b) the downstream end of the passive separator.

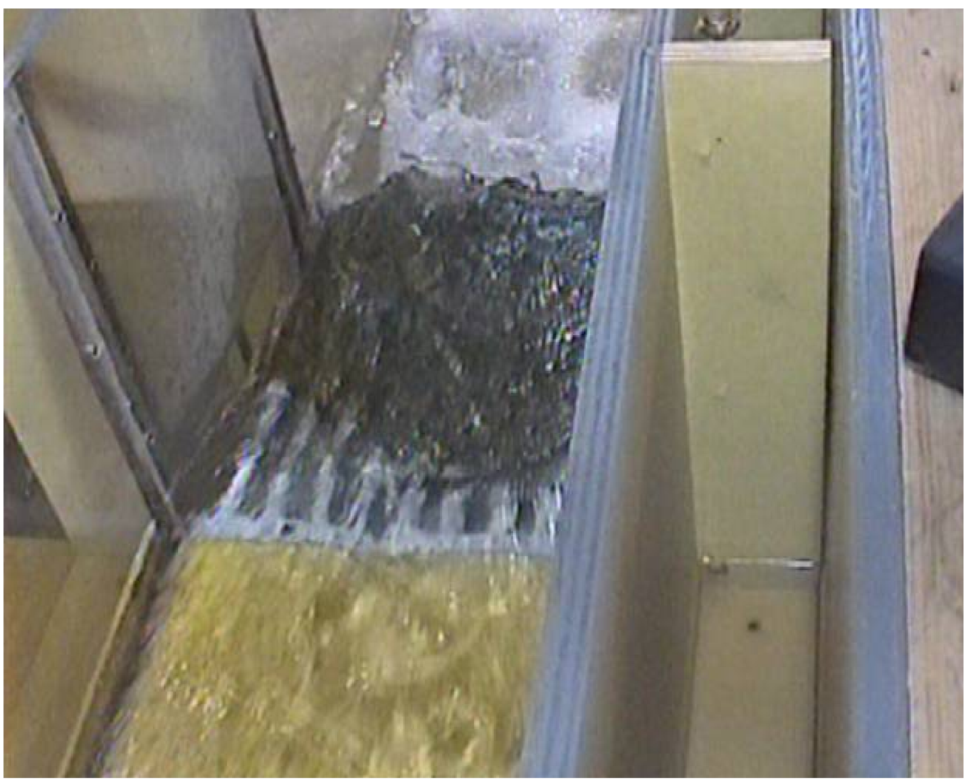

FIGURE 15.—Debris collects at downstream end of active separator.

FIGURE 16.—Cross members supporting bar rack structure are replaced with 1 inch coated, rotating roller and a 2-inch rotating roller at downstream end of passive separator (near top of picture).

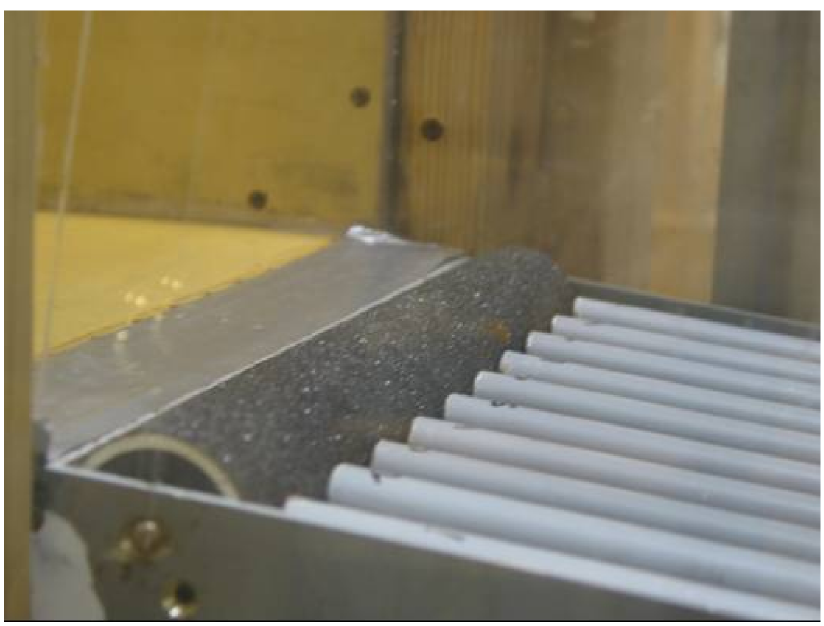

FIGURE 17.—The 2-inch rotating roller is elevated at the downstream end of the passive separator to prevent debris from collecting in the joint between the separator and the solid platform.

FIGURE 18.—Looking down on the passive separator with debris rollers installed.

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APPENDICES

Appendix 1 – Literature and State-of-the-Art Review

Appendix 2 – Results of Statistical Analyses

APPENDIX 1 – LITERATURE AND STATE-OF-THE-ART REVIEW

Separator research and development has focused on two areas:

- Development of continuously operated separators that would be used to segregate predator fish from prey fish, with the objective of reducing handling stress and predation in fish salvage efforts where fish are collected for bypass and transport

- Development of separator designs that could be intermittently applied at aquaculture facilities, with the objective of sorting or concentrating stock

Although quite different in application objectives, findings from both study areas give insight into design and operation features that generate effective separation performance.

The studies present two alternative separator-operating modes: passive and active. Passive separators use fixed separators that depend on fish behavior and fish response to achieve fish passage and sorting. They consider hydraulics and fish response to create situations that encourage fish to pass through the separator but do not force passage. Active separators physically pass all flow through the separator or physically sweep the separator through the flow, thus requiring the fish to either pass through the separator or be retained directly by the separator (if the fish are too large to pass).

Passive separators reduce fish injury potential because the fish are not forced to come in direct contact with the separator; however, they are less effective because they depend on fish response to achieve separation. Passive separators are not widely applied in aquaculture; thus, the concept is less proven and is more developmental. Passive designs include separators (typically bar arrays) placed horizontally or on a slight incline (McComas *et al*., 1996; McComas *et al*., 1997; Katz *et al*., 1999) and separators placed vertically, similar to a wall (communication with Jim Congelton, University of Idaho). Typically, flow sweeps past the separator element.

Active separators achieve high sorting efficiencies by plunging flows through the bar rack, forcing the fish to pass through. If the fish are small enough to physically pass the separator, they will pass, but larger fish are retained. Because of the nature of active separators, fish come in direct contact with the separator and the potential for fish injury is increased. Applied active separators include horizontal and vertical bar arrays through which a flow field is passed, separator panels that are swept through the flow (holding pools or raceways), and baskets that are vertically raised through holding tanks. Literature is extremely sparse regarding active separators and none was located; however, communication with Daniel Lance (Lance Industries), Michael Timmons

(Cornell University), and Harry Westers (aquaculture consultant) gave insight into performance considerations with passive separators. Parameters that should be considered with separator development include:

- **Fish response** – Fish reaction or response to the separator surface and the flow field will vary with species, as well as between developmental stages. Fish reaction and response can substantially influence passive separator performance. McComas *et al*. (1997) found that, for a specific separator design and operation, separation efficiencies ranged from 50 to 85 percent for various salmonid species (Chinook, coho, sockeye, steelhead). Michael Timmons noted that his observation of typical fish responses to separators indicates a sounding movement. Based on this, Timmons speculated that an inclined separator bar rack might be most effective. Timmons also suggested that any passive separator concept pursued should be evaluated for all major and significant species to be encountered at Tracy Fish Collection Facility (TFCF). Field evaluation for separator designs may prove ineffective for some species. Field testing and refinement at the TFCF facility are prudent. A combined use of passive and active separators may be necessary to achieve effective separation for all species at the TFCF.

- **Flow conditions** – Timmons observed that to achieve effective separator performance, it is critical that a velocity and attraction field be generated to properly orient fish to the separator. He also indicated that if fish orientation and separator design are not correct, the fish will come into contact with the separator and avoid it. Timmons also pointed out that the pectoral fin is a critical contact point and that once the fish's head enters the separator, the fish will pass through.

Flow velocity passing the separator and flow depth over the separator or flow width passing the separator (for vertical separators) also will influence performance. Katz *et al*. (1999) evaluated horizontal separators with flow velocities of 1.0 and 2.0 meter per second (m/s) at submergences of 50 millimeter (mm) and 100 mm over the separator. Higher separation efficiencies were achieved with the shallower flow depths and higher velocities. Part of this may be due, in part, to the development of standing waves that yield very shallow submergences at the wave troughs. Conversely, McComas *et al*. (1997) found that inclined separators (4- and 8-degree adverse slopes) with a water depth of 30 mm over the downstream end of the separator achieved higher separation efficiencies with a 1.0 m/s sweeping velocity, rather than with a 2.0 m/s sweeping velocity. Secondary flow features such as submerged water jets spraying up through the separator (that were intended to function as a fish attractant) were also evaluated; however, these water jets showed no advantage. Katz, in conversation, observed that the mechanics of fish separation and the influence of secondary flow features such as standing waves and flow jets are not fully understood. In this conversation, Katz noted that to minimize injury of more fragile species, sweeping velocities less than 2.0 m/s are more appropriate.

McComas also notes that flow conditions behind or below the separator must be considered and refined, both to initially encourage fish passage through the separator and then to move fish away from the separator. Supplemental flow may have to be introduced behind the separator to generate a well-directed flow field with a large enough flow cross section to attract fish.

Separator configuration and length, and its combined influence of flow depths and flow velocity, as well as fish species, sizes, and behavior, must be considered in the development of the separator design. The majority of passive separator research that has been conducted by McComas *et al*. (1996 and 1997) and Katz *et al*. (1999) has focused on horizontal and slightly inclined (4- and 8-degree adverse slopes) separators. Timmons, who has primarily worked with active vertical separators, also notes the sounding response observed with fish separator contact indicates that an adversely inclined separator is an appropriate design.

Congelton said that limited studies were conducted at McNary Dam on passive wall separators with vertical bars. Wall separators evaluated were not highly effective. A thorough effort, however, was not made to develop and refine this design. In conversation, McComas said that he did not think that a wall separator with horizontal bars would be effective with salmonid smolts. He indicated that wall separators with vertical bars might have potential. As previously stated, Congelton noted that separator performance depends strongly on fish behavior.

Passive horizontal separators ranging in length up to 12.0 m and slightly inclined separators ranging in length up to 4.5 m have been evaluated (McComas *et al*., 1997). The longer separators produced better separation efficiencies for both horizontal and slightly inclined separators. Based on these limited studies, it appears that horizontal or adversely inclined separators with a long separator length offer the best separation efficiencies.

Bar shape, spacing, and material: Separator design, including bar shape, free spacing between bars, and the material from which the separator is fabricated, will affect fish separator performance and the potential for fish injury. Bars with round cross sections are widely applied to eliminate sharp edges that can cause descaling and other fish injuries.

The spacing applied between bars depends on the separation objectives and the body size and shape of the target species. Fausch (1999) conducted a statistical analysis to identify the length and body width of fish that would be significant predators at the TFCF site and recommended separator bar spacing to Reclamation based on this analysis. Appropriate bar spacing is a starting point; however, field studies that evaluate separator performance when operating with all fish species and fish sizes present at the site must be conducted to refine and optimize separator design.

Materials that separators have been fabricated from include aluminum, clear acrylic, stainless steel, and gray polyvinyl chloride (PVC) bars. Daniel Lance stated that aluminum oxidizes, which leads to roughened surfaces and can cause fish injury. Lance said that stainless steel is an option; however, it is heavy and expensive and he recommended the use of acrylic materials. Timmons said that he initially used gray PVC and found that fish avoided it. Timmons found that use of clear acrylic bars substantially improved separator performance. McComas said that they used gray PVC the first year and then shifted to aluminum. Separation efficiencies were found comparable with both materials, and that there were no distinguishable difference in descaling and injury caused by the two materials. Part of this might be associated with differences in operation because the Timmons studies were conducted with application of the separator in aquaculture facilities, while the McComas studies were at a continuously operating field site.

Maintenance and debris handling: Debris fouling and cleaning was not addressed and was not a concern in any of the reviewed studies. Debris fouling was not an issue because of either the intermittent use or low debris loads present. Debris will clearly pose a problem at TFCF. Evaluation of fouling influences and debris removal techniques would best be achieved through studies at the TFCF site.

APPENDIX 2 – RESULTS OF STATISTICAL ANALYSES

We analyzed the dependent variable separation efficiency through a three-step process. First, we evaluated the assumptions of Analysis of Variance (ANOVA): Independence of observations, homogeneity of variance, and normality. Second, if the data met all the assumptions of ANOVA, we conducted ANOVA with the independent variable and raw separation efficiency. Third, if an assumption was violated, we performed a nonparametric test: Wilcoxon's Two Sample Test or Kruskal-Wallis Test (Sokal and Rohlf, 1981). All statistical analyses were conducted with Statistical Analysis Software, Version 8.0 (SAS Institute Inc., Cary, North Carolina).

Results of the Separator Angle Experiment:

For fathead minnow, neither angle nor velocity were significant at the 0.05 level (table A2-1).

TABLE A2-1

Species	Angle	Velocity in ft/s (cm/s)	Mean Efficiency (%)	Standard Error (SE)
Fathead minnow	2.25	2 (61)	96	2.0
Fathead minnow	2.25	4 (122)	86	7.2
Fathead minnow	5	2 (61)	81	7.5
Fathead minnow	5	4 (122)	92	5.6

Note: ft/s = feet per second; cm/s = centimeters per second.

For rainbow trout, angle was not a significant influence on separator efficiency. However, the p value for velocity was 0.0018. Therefore, we rejected the null hypothesis that the means were the same. We concluded the means for 2 ft/s (61 cm/s) were significantly smaller than for 4 ft/s (122 cm/s) (table A2-2).

TABLE A2-2

Species	Angle	Velocity in ft/s (cm/s)	Mean Efficiency (%)	SE
Rainbow trout	2.25	2 (61)	40	3.4
Rainbow trout	2.25	4 (122)	80	7.3
Rainbow trout	5	2 (61)	33	2.4
Rainbow trout	5	4 (122)	94	3.2

For splittail, a separator angle of 5 degrees produced higher separation efficiency, yet this result is not statistically significant. In addition, velocity was not statistically significant (table A2-3).

TABLE A2-3

Species	Angle	Velocity in ft/s (cm/s)	Mean Efficiency (%)	SE
Splittail	2.25	2 (61)	79	2.8
Splittail	2.25	4 (122)	70	7.6
Splittail	5	2 (61)	87	4.6
Splittail	5	4 (122)	92	4.1

In the experiments in which we tested a weak downwelling condition against a strong downwelling condition, angle was consistent across these trials at 5 degrees, and channel velocity was constant at 4 ft/s. We found fathead minnow (table A2-4) showed a slightly higher efficiency when a strong downwelling was present (Wilcoxon Two Sample Test, C = 19.50). For rainbow trout data, there was no statistically significant difference in the weak and strong downwelling conditions. We found splittail showed no statistically significant difference in the weak and strong downwelling conditions (Wilcoxon Two Sample Test, C = 16.0) (table A2-4).

Results for the "Downwelling" Experiment:

TABLE A2-4

Species	Downwelling	Angle and Velocity in ft/s (cm/s)	Mean Efficiency (%)	Significance
Fathead minnow	Weak	5, 4 (122)	92	$p = 0.0806$
Fathead minnow	Strong	5, 4 (122)	100	$p = 0.0806$
Rainbow trout	Weak	5, 4 (122)	94	NS[1]
Rainbow trout	Strong	5, 4 (122)	78	NS
Splittail	Weak	5, 4 (122)	92.3	NS
Splittail	Strong	5, 4 (122)	87.5	NS

[1]No significance.

We tested a configuration we thought to be optimum. The "optimum" configuration appeared to be a downwelling condition with a 5-degree separator angle and a channel velocity of 4 ft/s. This is indicated in table A2-5 by Optimum = 1. We opted to use the nonparametric, one-way Kruskal-Wallis (KW) test because of the very low sample sizes (n = 3). For the fathead minnow, the KW showed that the optimum condition is not statistically different from the suboptimal condition (p = 0.5127). For rainbow trout, the optimum configuration was statistically different than the other configurations, KW (p = 0.0495) and ANOVA (p = 0.0492). There was no statistical difference between optimal and sub-optimal conditions for splittail (p = 0.1266).

Results for the "Optimum" Experiment:

Table A2-5

Species	Optimum	Angle and Velocity in ft/s (cm/s)	Mean Efficiency (%)	Significance
Fathead minnow	0	2.25, 2 (61) 2.25, 4 (122) 5, 2 (61)	87.7	p = 0.5127
Fathead minnow	1	5, 4 (122)	92	p = 0.5127
Rainbow trout	0	2.25, 2 (61) 2.25, 4(122) 5, 2 (61)	51.6	p = 0.0495
Rainbow trout	1	5, 4 (122)	93.75	p = 0.0495
Splittail	0	2.25, 2 (61) 2.25, 4 (122) 5, 2 (61)	78.6	p = 0.1266
Splittail	1	5, 4 (122)	92.3	p = 0.1266

The "optimum" was significantly better for only one species in a statistically demonstrable way: rainbow trout (table A2-5). In addition, for rainbow trout, we believe that the "optimum" configuration was significant because of the strongly significant influence of approach velocity (p = 0.0018).

More fish appeared to go through the passive separator when the experimental arena was spotlighted by two General Electric dual 500-watt incandescent bulbs placed 2.6 m (8.5 ft) from the separator but outside the experimental arena. To investigate this further, we performed three replicates of the PAV2 (channel velocity of 2 ft. per second and 0.2 approach velocity) configuration with the spotlights. We tested the mean efficiencies of each species and added a bottom-oriented species: white sucker for the passive-active configuration and for the lighted condition versus an unlighted condition.

Results for the spotlight data:

TABLE A2-6b

Species	Mean Passive Efficiency		Statistical Significance	Result
	With Lights	Without Lights	p value	
Splittail	79.1	50.2	p = 0.0495	Significant
Rainbow trout	79.5	78.3	p = 0.5066	NS[1]
Flathead minnow	75.6	77.8	p = 0.8273	NS
White sucker	94.2	97.0	*p = 0.1367	NS

* = Wilcoxon's Two-Sample Test, t approximation
[1]No significance

TABLE A2-6b

Species	Mean Total Efficiency		Statistical Significance	Result
	With Lights	Without Lights	p value	
Splittail	86.0	100.0	p = 0.1213	NS[1]
Rainbow trout	88.3	100.0	p = 0.3173	NS
Flathead minnow	93.7	100.0	p = 0.1213	NS
White sucker	98.5	98.4	p = 0.7963	NS

[1]No significance

For the passive efficiency spotlight data, we found only the splittail result to be significant. For mean total efficiency, we detected no difference with and without lights for any species. Therefore, when the spotlights are on, splittail use the passive separator more efficiently. However, splittail total efficiency did not increase. Therefore, it seems that some proportion of the fish that would have been separated by the active separator are instead separated by the passive separator. This could provide less physical injury to the fish. Thus, having the lights on over the passive separator may improve splittail survival.

We conducted replicates at each of three passive separator configurations: (Approach Velocity and Channel Velocity): (1) $V_a = 0.2$ ft/s and $V_c = 2$ ft/s, (2) $V_a = 0.3$ ft/s and $V_c = 3$ ft/s and (3) $V_a = 0.4$ ft/s and $V_c = 4$ ft/s. We collected passive separator and total efficiency in each replicate. We found both the passive efficiency and total efficiency data to be distributed normally for each species. Thus, we ran two ANOVAs using configuration as the independent variable and testing each of these dependent variables: (1) passive efficiencies and (2) total efficiencies.

Results for the Three Configurations:

Splittail

Passive efficiency was not significantly different statistically ($p = 0.0992$) for approach velocities (V_a) using the traditional Type I Error rate of 0.05. However, the p value was quite small and we closely inspected the V_a values. Upon inspection, we found the passive efficiency at $V_a = 0.2$ (50.2percent) and at $V_a = 0.3$ (58.6percent) to be similar and greater than $V_a = 0.4$ (25.6percent) (table A2-7a). Therefore, we pooled passive efficiencies for $V_a = 0.2$ and $V_a = 0.3$. We found, when pooled, the V_a does influence passive efficiency in a statistically significant manner ($p = 0.0389$) (table A2-7b).

TABLE A2-7a

Species	Mean Passive Efficiency			Statistical Significance	Result
	Va = 0.20	Va = 0.30	Va = 0.40	p value	
Splittail	50.2	58.6	25.6	p = 0.0992	NS
Rainbow trout	77.2	81.2	69.3	p = 0.2521	NS
Flathead minnow	66.0	69.9	76.4	p = 0.1479	NS
White sucker	97.0	92.9	93.4	p = 0.2357	NS

TABLE A2-7b

Species	Mean Passive Efficiency		Statistical Significance	Result
	V_a = (0.20 + 0.30) Pooled	V_a = 0.40	p value	
Splittail	54.4	25.6	p = 0.0389	Significant
Rainbow trout	79.2	69.3	p = 0.1213	NS
Flathead minnow	68.0	76.4	p = 0.0707	Close
White sucker	94.9	93.4	p = 0.5169	NS

Total efficiency was not significantly different statistically ($p = 0.0628$) for approach velocities (V_a) using the traditional Type I Error rate of 0.05; however, upon inspection, we found the passive efficiency at $V_a = 0.2$ (96.0percent) and at $V_a = 0.3$ (95.6percent) to be similar and greater than $V_a = 0.4$ (70.9percent) (table A2-8a). Therefore, we pooled total efficiencies for $V_a = 0.2$ and $V_a = 0.3$. We found, when pooled, the V_a does influence total efficiency in a statistically significant manner ($p = 0.0196$) (table A2-8b).

TABLE A2-8a

Species	Mean Total Efficiency			Statistical Significance	Result
	Va = 0.20	Va = 0.30	Va = 0.40	p value	
Splittail	96.0	95.6	70.9	p = 0.0628	Close
Rainbow trout	97.3	92.1	92.5	p = 0.5611	NS
Flathead minnow	97.7	90.5	94.9	p = 0.276	NS
White sucker	98.5	99.1	96.5	p = 0.6884	NS

TABLE A2-8b

Species	Mean Total Efficiency		Statistical Significance	Result
	Va = (0.20 + 0.30) Pooled	Va = 0.40	p value	
Splittail	95.8	70.9	p = 0.0196	Significant
Rainbow trout	94.7	92.5	p = 0.4386	NS
Flathead minnow	94.1	94.9	p = 0.5994	NS
White sucker	98.8	96.5	p = 0.3961	NS

Rainbow Trout

No significant result for approach velocities of .2 versus .3 versus .4. This is true for passive and total efficiency (tables A2-7a, A2-7b, A2-8a, and A2-8b).

Fathead Minnow

No significant result for approach velocities of .2 versus .3 versus .4. This is true for passive and total efficiency (tables A2-7a, A2-7b, A2-8a, and A2-8b).

White Sucker

No significant result for approach velocities of .2 versus .3 versus .4. This is true for passive and total efficiency (tables A2-7a, A2-7b, A2-8a, and A2-8b).